SIRAS-G, the Spaceborne Infrared Atmospheric Sounder for Geosynchronous Earth Orbit

PI: Thomas Kampe

The SIRAS-G Team:
Dan Michaels, Paul Hendershott, Gary Mills, Brian Johnson, Holden Chase, Peter Johnson, John Wassmer, Tim Valle

Ball Aerospace & Technologies Corp.
1600 Commerce St. Boulder, CO 80301

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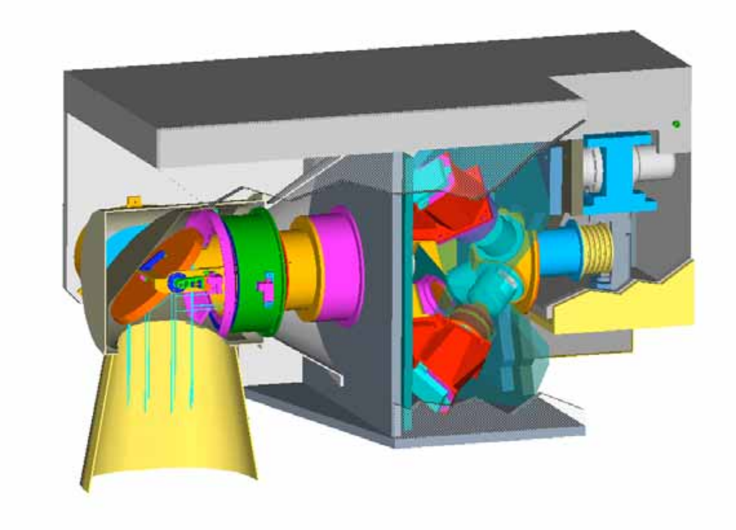
SIRAS-G: Spaceborne Infrared Atmospheric Sounder for Geosynchronous Earth Orbit

Description

- 4 cooled grating spectrometers
- Spectral coverage: 3.75 – 15 μm
- Large format 2-D detector arrays for simultaneous spatial & spectral info.
- Imaging with very low spectral smile and keystone distortion
- Warm shield design to reduce background



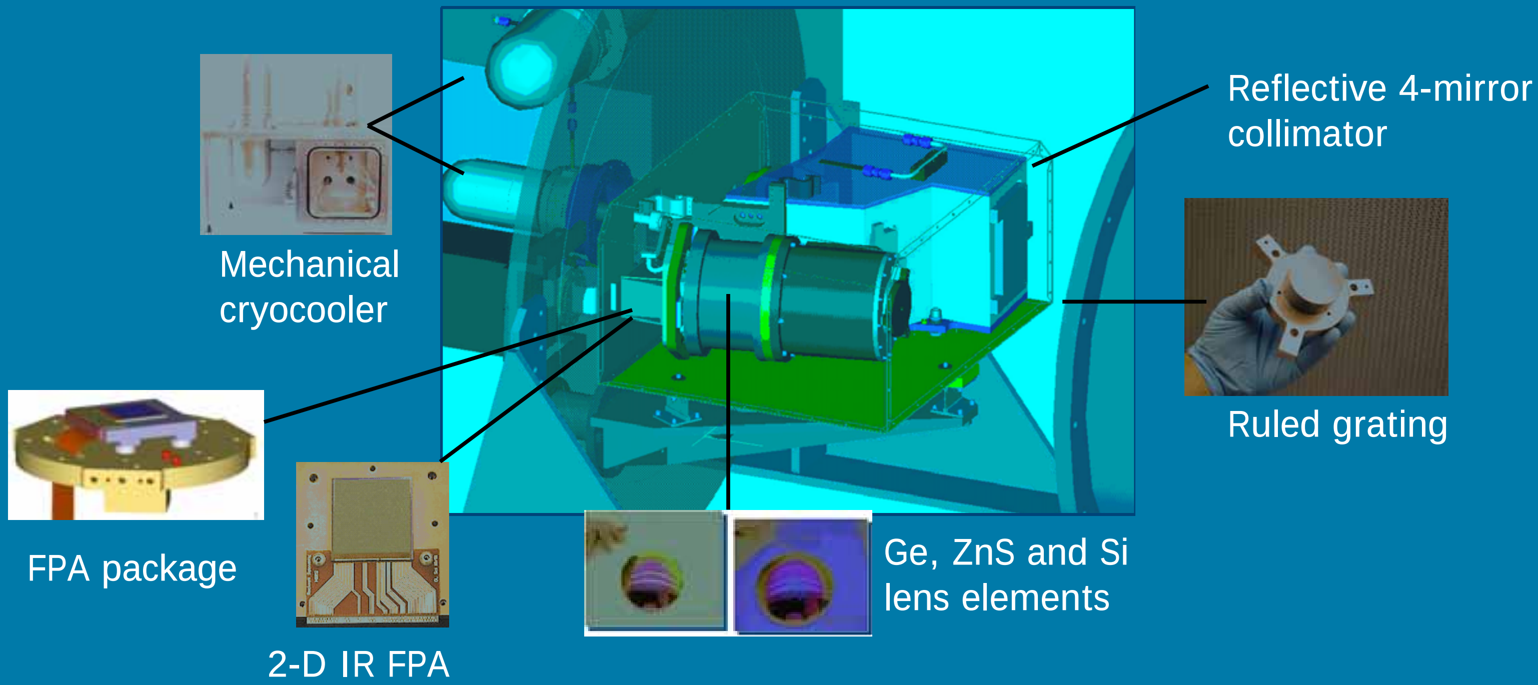
SIRAS-G Imaging Spectrometer Concept

NASA Instrument Incubator Program:
- development of innovative remote-sensing concepts
- Emphasis on smaller, lower power sensors

Table 1. SIRAS -G Grating Spectrometers

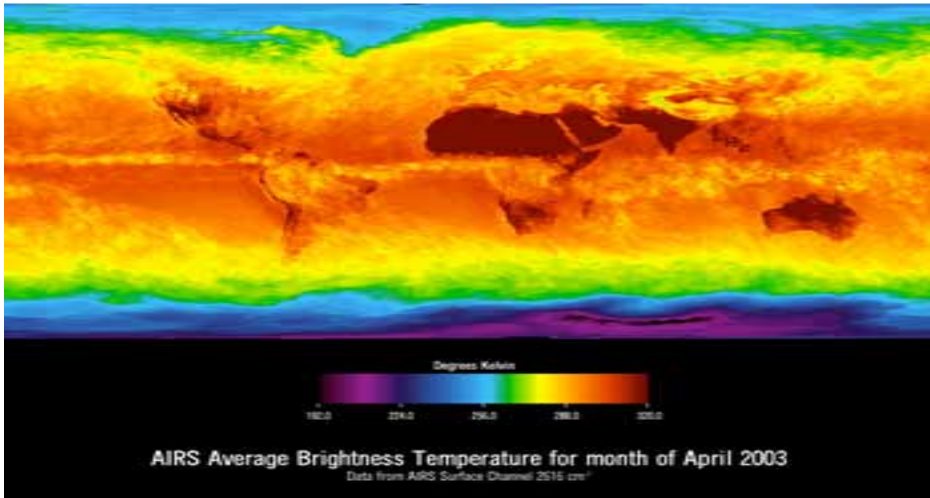
Spect	Band (μm)	Comments
1	3.35 -4.8	Build in 2003 IIP
2	6.2 -8.22	Design in 2003 IIP
3	8.8 -12.0	Design in 2003 IIP
4	12.3 -15.4	Built in 1999 IIP

MWIR Spectrometer Demonstration



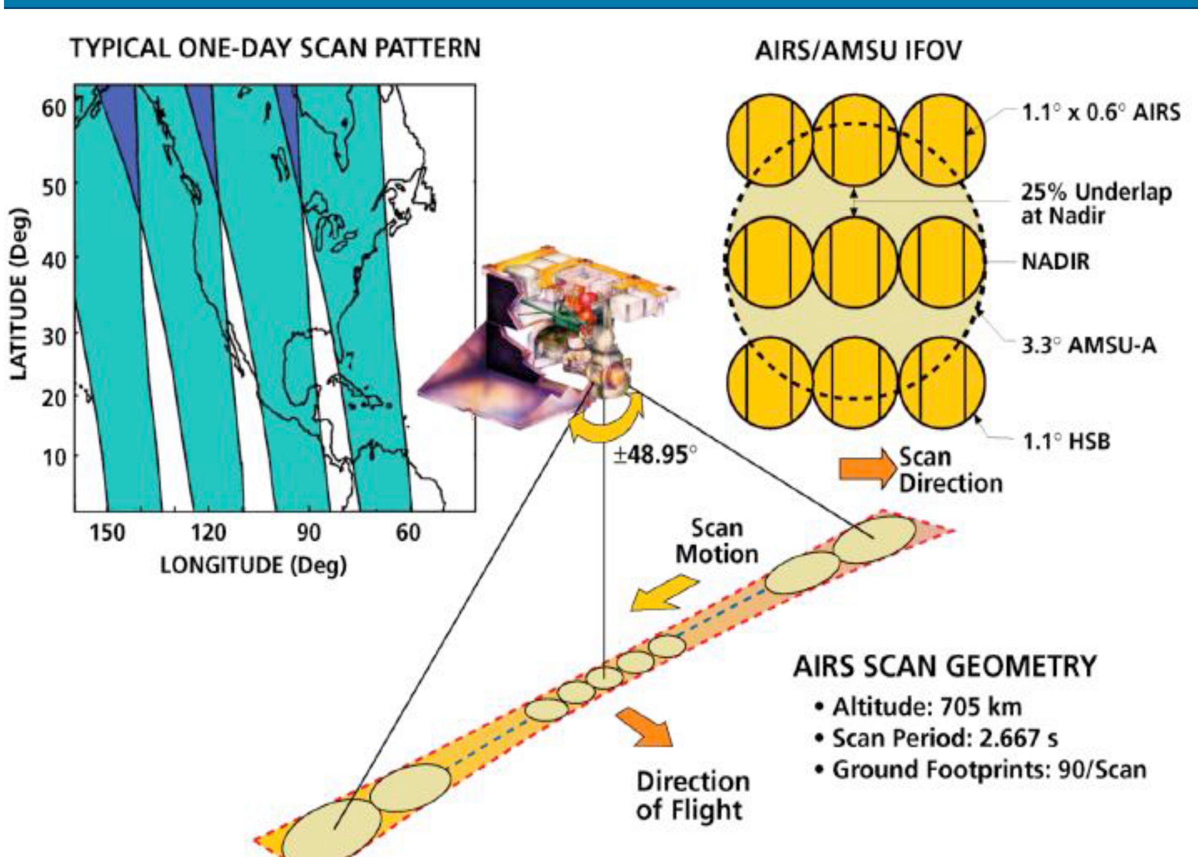
SIRAS-G MWIR spectrometer mechanical layout and component technologies being demonstrated under NASA's Instrument Incubator Program

- *advanced 1024x1024 mid-infrared detector array and custom dewar*
- *germanium and silicon lens elements for refractive camera assembly*
- *Ball's 3rd generation SB235 Stirling cycle mechanical cooler*
- *ruled infrared grating*
- *reflective collimator*



SIRAS-G History

- SIRAS was originally conceived as a smaller, lower mass, less costly follow-on instrument for AIRS (Atmospheric Infrared Sounder)

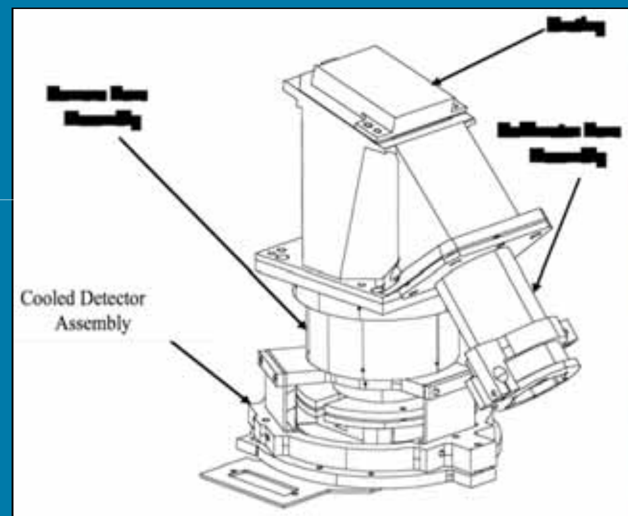


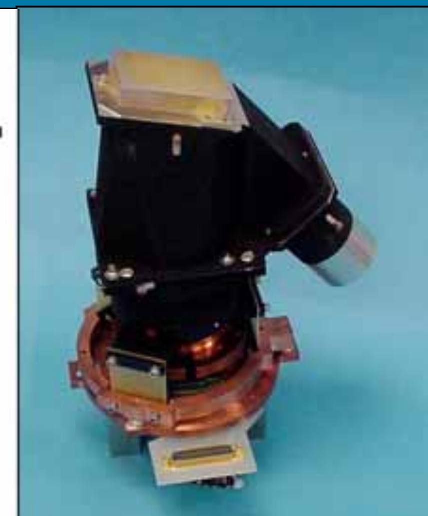
Care of the NASA AIRS Program Web Page

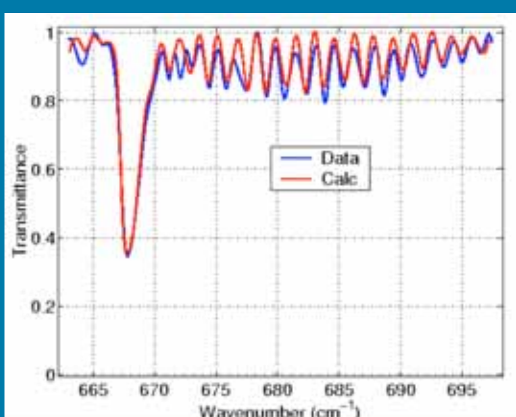
- In 1999, JPL headed up the Spaceborne Infrared Atmospheric Sounder (SIRAS) IIP
- PI: Harmut Aumann (JPL, Chief Scientist on AIRS)
- Technical Lead: Tom Pagano (JPL, AIRS Program Manager)
- Ball Technical Lead: Tom Kampe

SIRAS-1999 IIP - What Was Achieved?

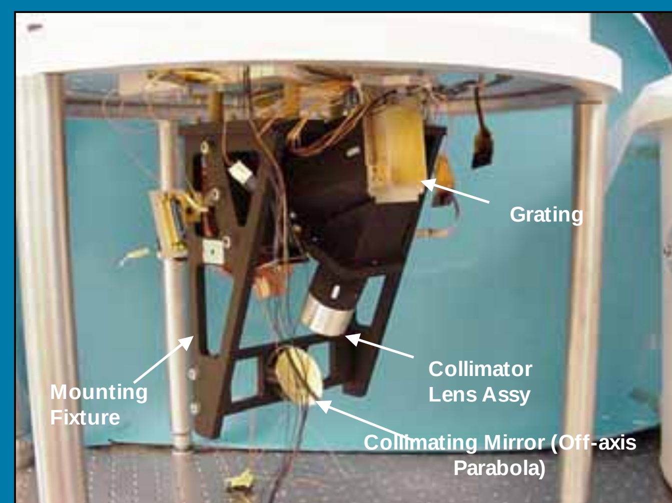
- Designed, built & cryogenically tested 12-15.4μm spectrometer
  - Selected the LLWIR spectrometer since it represented the greatest challenge (material choices, detector cut-off, etc.)
- Developed test facilities for testing the spectrometer at cryogenic temperatures
- Integrated an AIRS detector array
- Developed data collection and control software
- Effort completed in 12-months





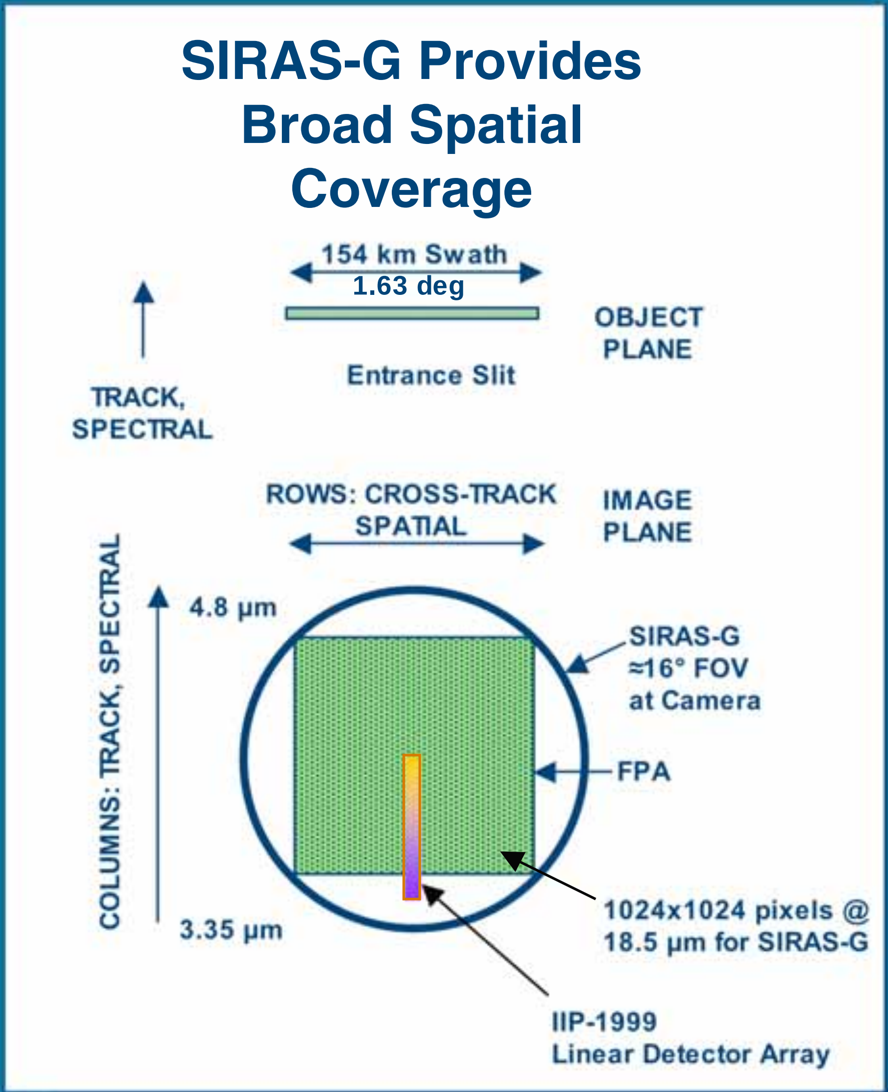


- Spectral resolution determined by comparing to theoretical 3-m path atmospheric transmission spectra with varying spectral response widths
- Response widths varied until convolved modeled spectra matched measured spectra
- Measured CO_2 spectra show spectral resolution of >900 achieved



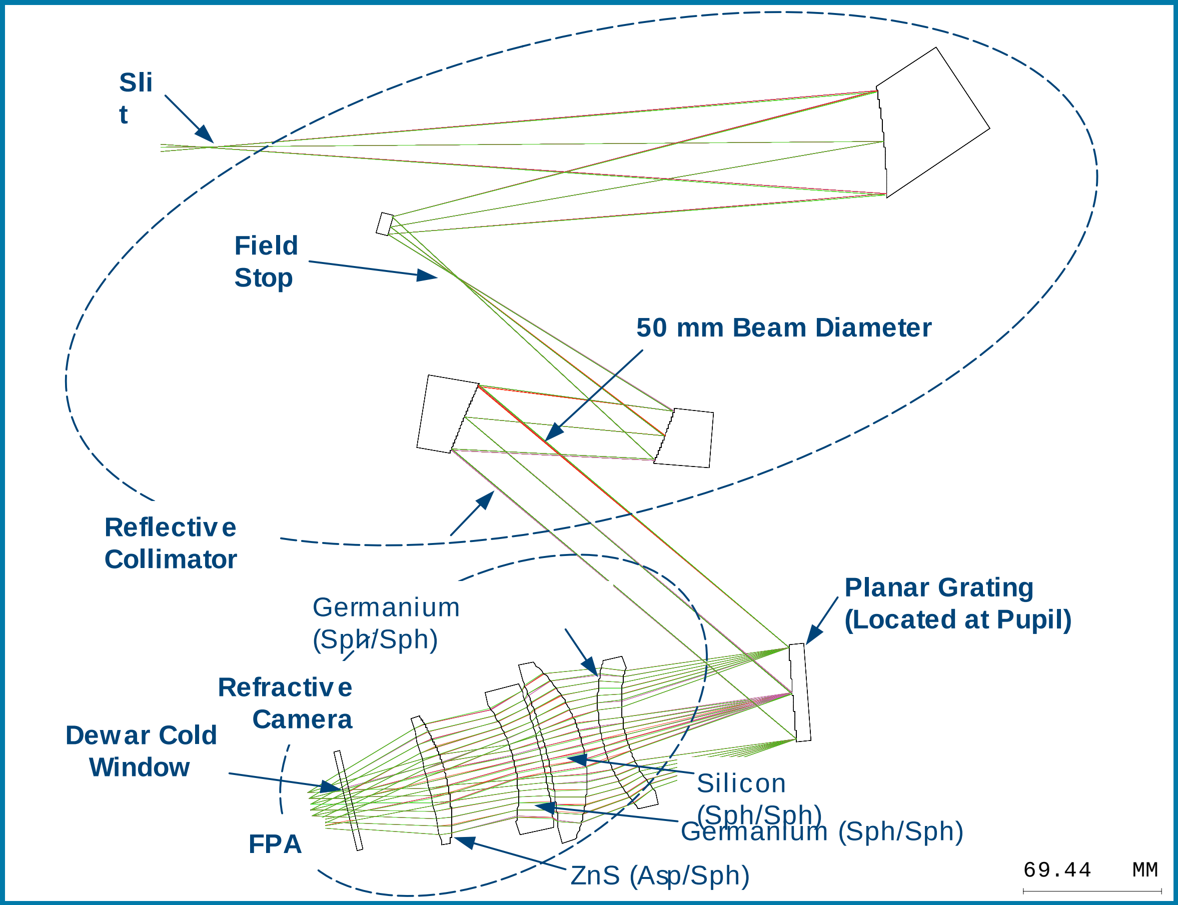
SIRAS SPECTROMETER IN TEST DEWAR

How Does SIRAS-G Differ From SIRAS?



- The Spectrometer on SIRAS imaged a single ground IFOV and the spectrum was dispersed along a linear detector array.
- For SIRAS-G, we are building a true imaging spectrometer
  - Here, we have an appreciable 16^0 spatial FOV in the camera imaged along *rows* of detectors
  - Spectral information dispersed in the orthogonal direction, along *columns* of detectors
  - Control of Spectral Smile and Keystone Distortion are critical
    - For the baseline design, these are controlled to less than 20% of a spectral sample (i.e., 2 pixels) across full FOV

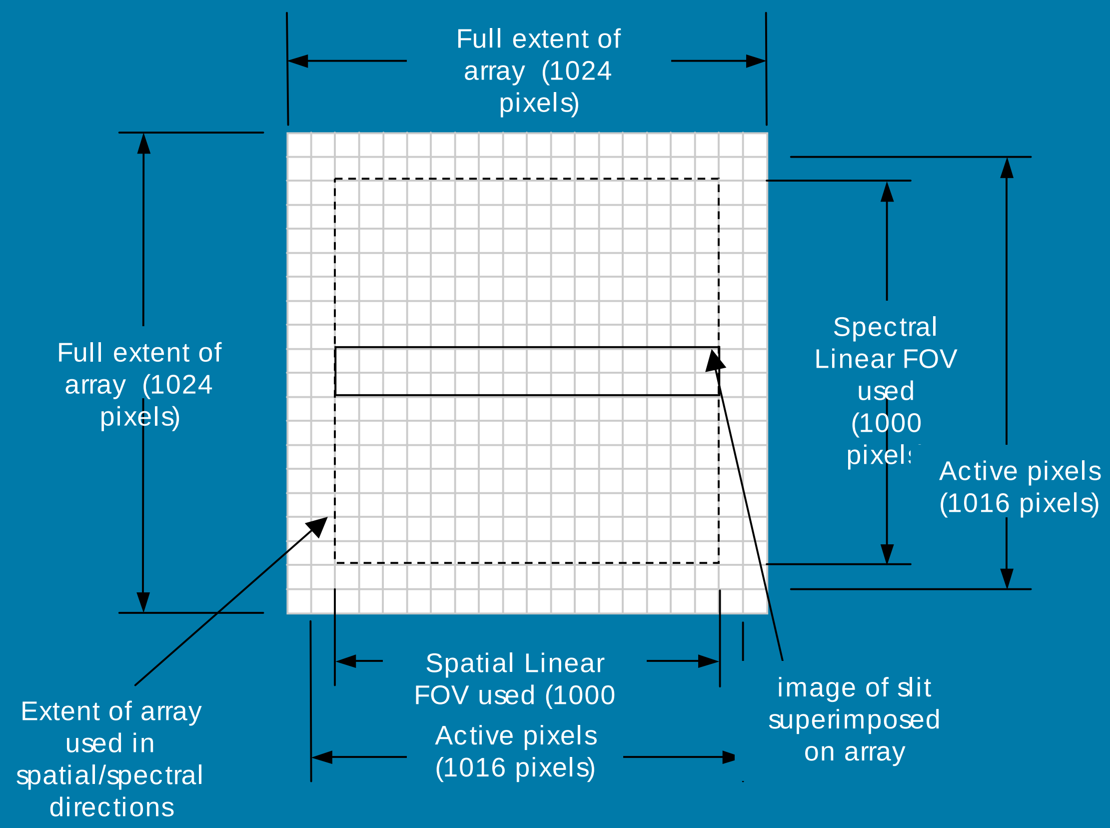
Aft-Optics Design Controls Distortion on Large FPA



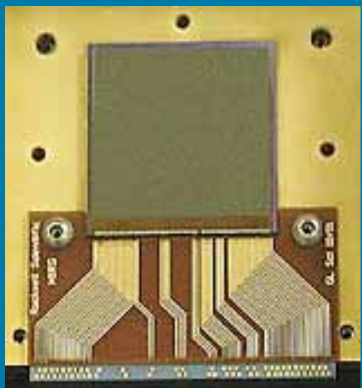
- Demo Inst. using RSC Hawaii 1-RG Array (1024x1024, 18.5mm pixels)
- Distortion controlled to less than 20% of spectral sample over FPA
- Spatial and spectral resolution elements = 2 pixels
- Slit width = 2 pixels (Nyquist sampling)
- Slit length = 37.0mm, or 1000 pixels
- 4-mirror collimator – all mirrors diamond-turned
- Flat blazed grating
- Refractive 4-element camera
- Operational temp: 140 K

Demo Instrument Optimized for Large Format Array

- RSC Hawaii 1-RG Array
- 1024 x 1024 Format Array
- 0.0185-mm Pixel Pitch
- Spatial and spectral resolution elements = 2 pixels
- Slit image is smaller in length than FPA
    - Avoids illuminating inactive pixels or leads & wires around FPA
    - Provides margin for alignment of FPA to slit
    - Since ends of slit are on active pixels, alignment of the slit can be measured

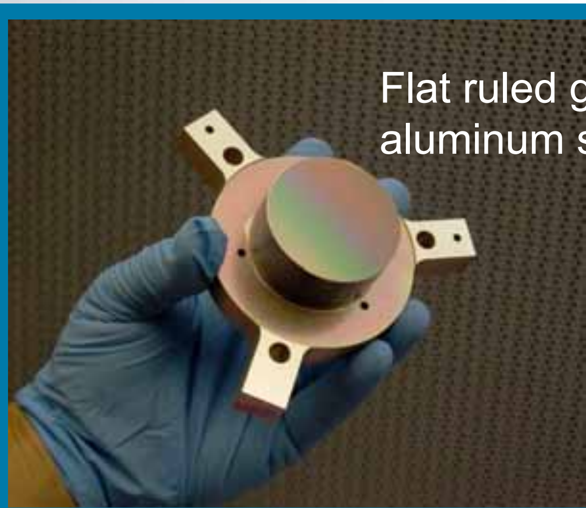


Major hardware Elements Ready for Integration

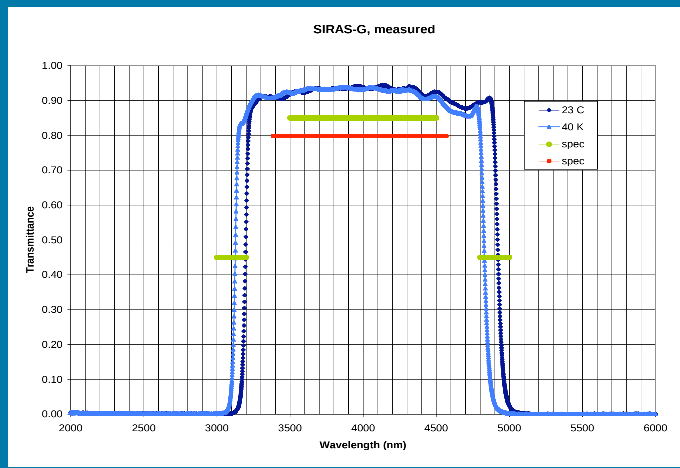


1024 x 1024 HgCdTe
5.2 µm cut-off FPA

Ball SB235 Cryo-Cooler



Flat ruled grating,
aluminum substrate



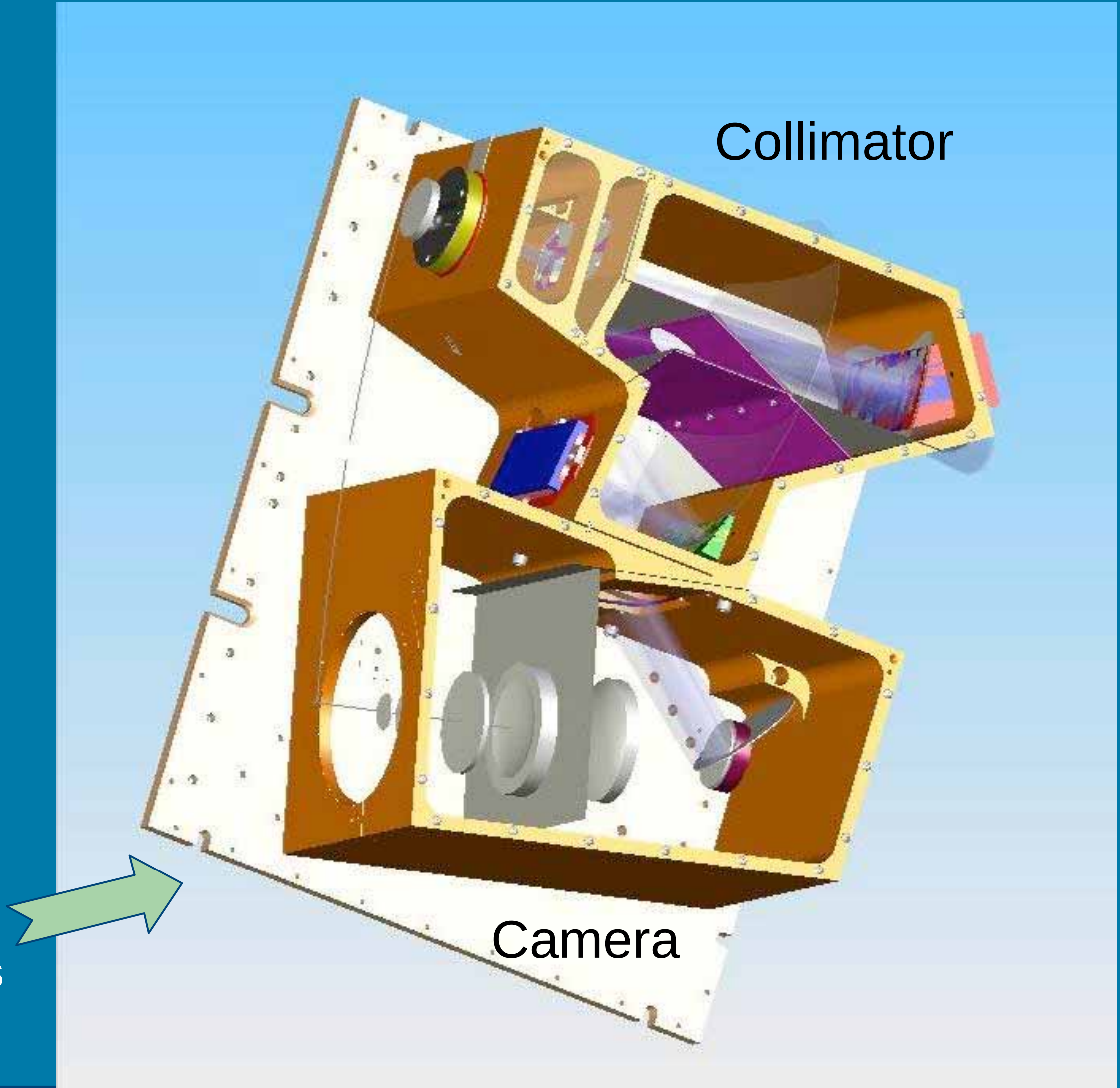
Cold filter exhibits excellent in-band transmission and OOB rejection

Ge, Si, and ZnS camera
lens ready for integration

Collimator/Optical Bench Design

- OBA is all aluminum construction
- Mirrors are single point diamond-turned on aluminum substrates
- Fiducials on mirrors provide positional & angular information for mirrors, grating, slit & camera to OBA master coordinate frame

Layout from SolidWorks Model



Reflective Triplet Objective (RTO) focuses Scene Energy onto Slit

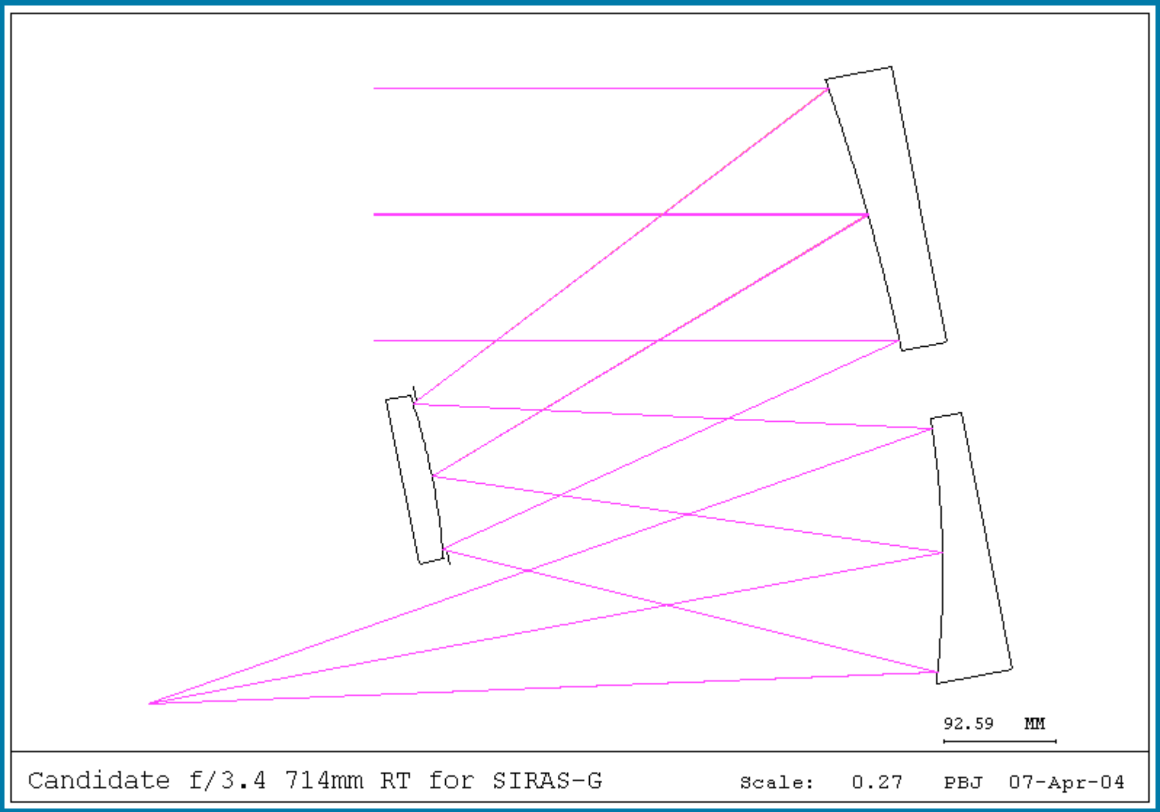


Figure 1.0 SIRAS-G Reflective Triplet Objective with Spherical Secondary

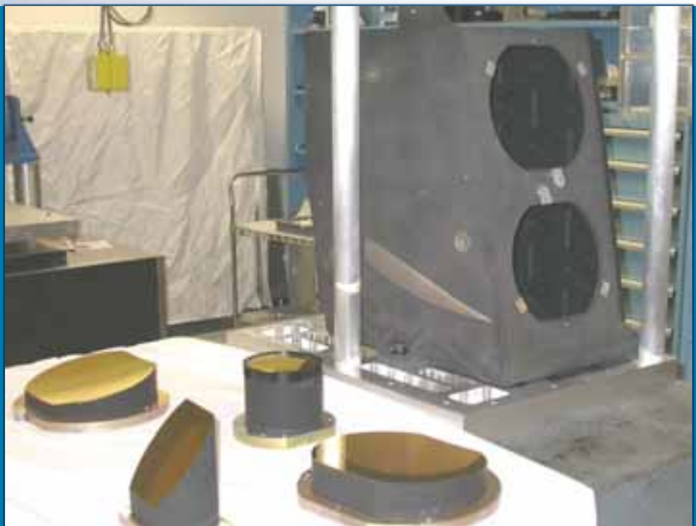
Design Trade Study Resulted is Selection of RTO for Lab Demo:

- Diffraction limited performance over slit field (@4 microns wvl)
- Diffraction limited spot size consistently 36-µm (84% encircled energy)
- No central obscuration
- Less fabrication and alignment sensitive than comparable TMA
- All mirrors tilted at same angle
- No Y-decenter for vertex of all parent mirrors
- Spherical Secondary
- No higher-order aspheres
- Telecentric in image (slit) space
- Low Cost!

- TMA with internal field stop would be selected for flight system

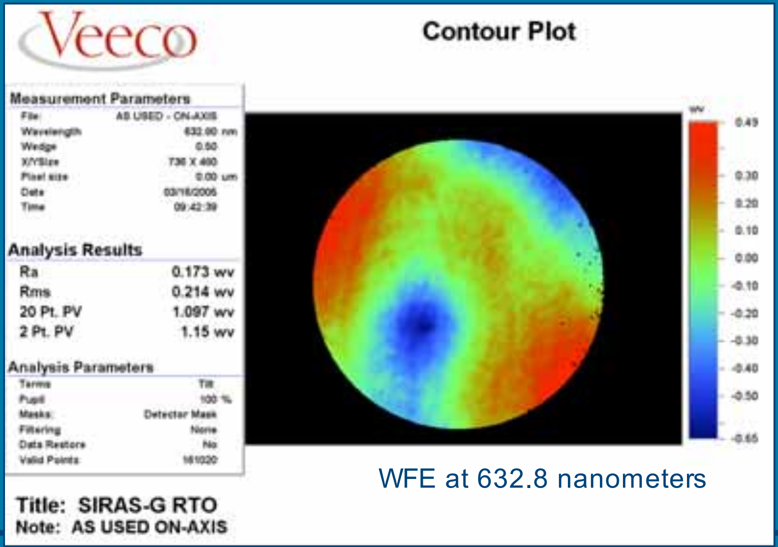
The Reflective Triplet Objective (RTO) is Complete

- RTO delivered to BATC on 03/24/05
- All performance requirements met
- WFE is 0.25 waves RMS @ 632.8-nm
  - Corresponds to ~0.04 waves RMS at operational wavelength of 4.0-µm
- Mirror Surface Roughness: < 100 λ RMS (diamond-turned - no post-polishing)



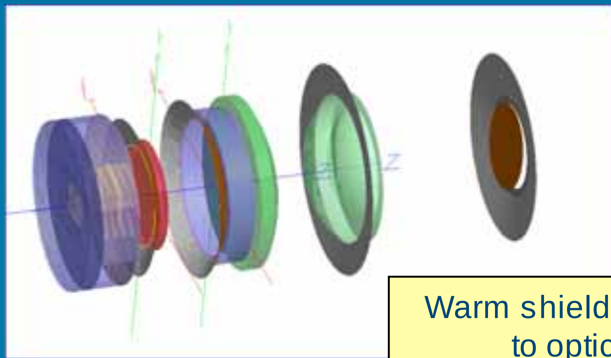
RTO Housing and Mirrors prior to final assembly

RTO during Optical Testing at Corning NetOptix

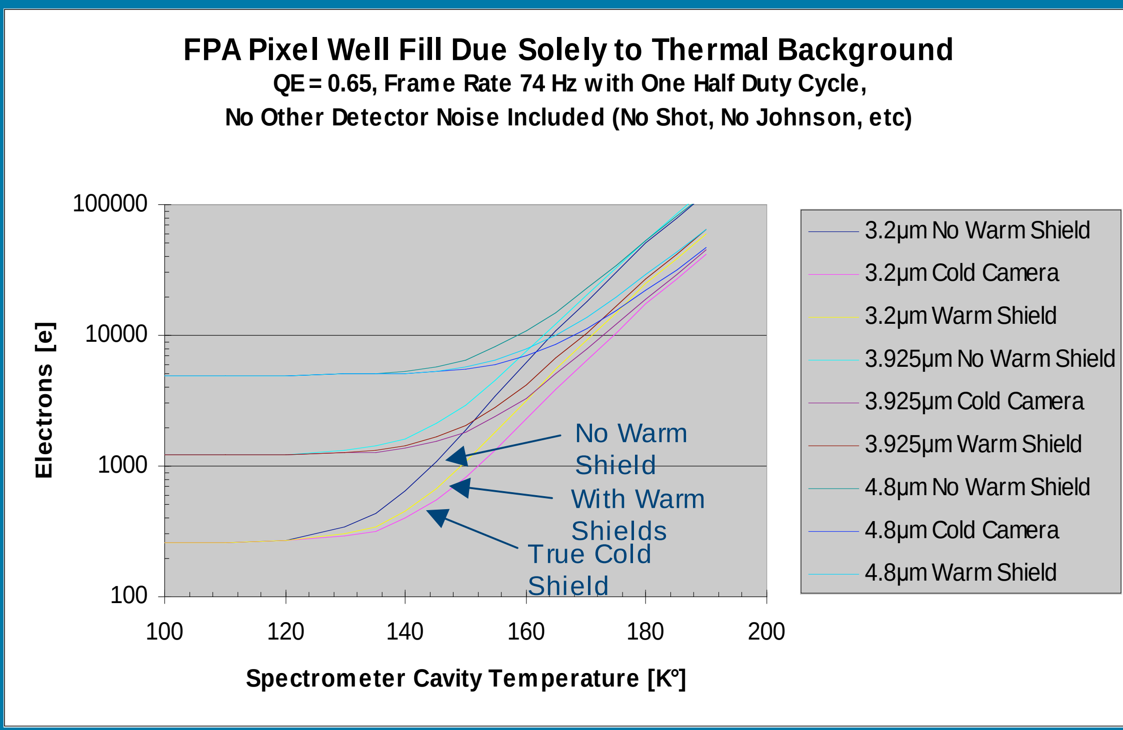


WFE at 632.8 nanometers

Reflective Warm Shield Demonstration



Warm shield locations relative to optical surfaces

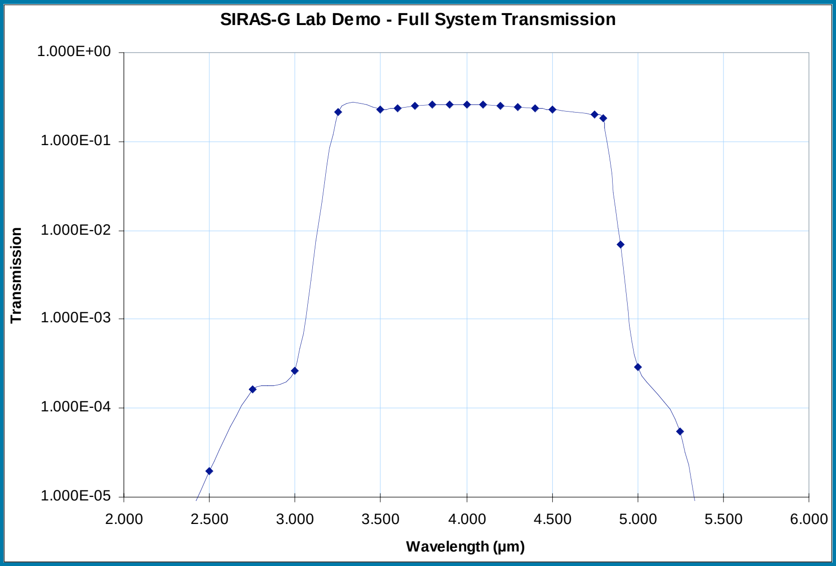


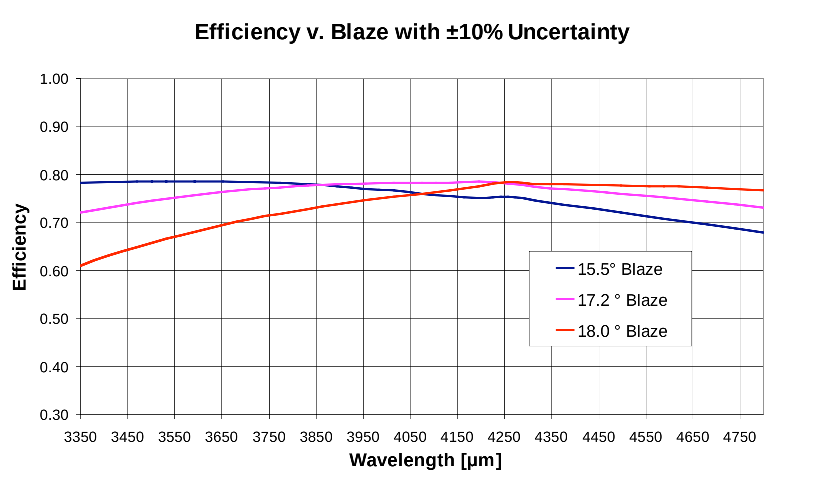
Pixel well fill due to thermal background alone as function of the spectrometer cavity temperature.

- Demonstrates Multi-Stage Warm Shield Concept in Lab Demo
  - High performance multi-stage warm shield eliminates need for true cold shield
  - First known application of warm shields to IR imaging spectrometers
- Mature design methodology in place to support warm shield designs for additional wavelength ranges, etc.
  - Design, geometry and warm shield positioning well understood for extrapolation to other spectrometers
- Predicted thermal noise well fill <5.5% full well
- Plan is to test with & without warm shields
  - Will yield experimental verification of warm shield performance

Transmission Analysis Updated With As-Built Data

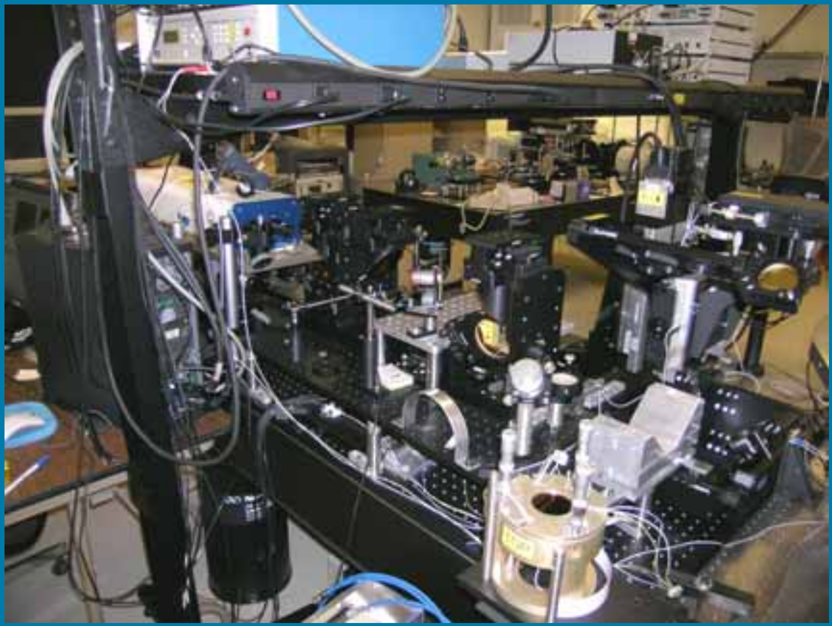
- Transmission analysis indicates good throughput for as-built system
- Transmission analysis accounts for test facility beam delivery throughput, mirror reflectivity, lens internal transmission and coatings, filter transmission, diffraction, obscuration effects and grating efficiency
- Potential performance impacts due to grating blaze angle uncertainty, etc. accounted for in transmission analysis





Performance Test Methodology is in Place

- **Test methods and facilities in place to support testing of key performance parameters**
  - **Keystone Distortion**
  - **Spectral Smile**
  - **Modulation Transfer Function (MTF)**
  - **Spectral Response Function (SRF)**
  - **Dispersion**
- **Test methods and facilities developed on Ball IR&D funds**
  - **Ball Proprietary (patent pending)**
- **Tests broad range of Hyperspectral Instruments**
  - **VIS/NIR thru LWIR**



Mission Concept Studies Initiated

- **First mission studied is an AIRS Follow-On Mission**
  - Low-Earth Orbit; enhanced spatial resolution
  - Mission focused on retrieval of atmospheric temperature profiles, water vapor profiles, ozone column and cloud properties
  - Spectral coverage and resolution optimized for these parameters

Candidate AIRS Follow-On Mission

Key Measurement Requirements:

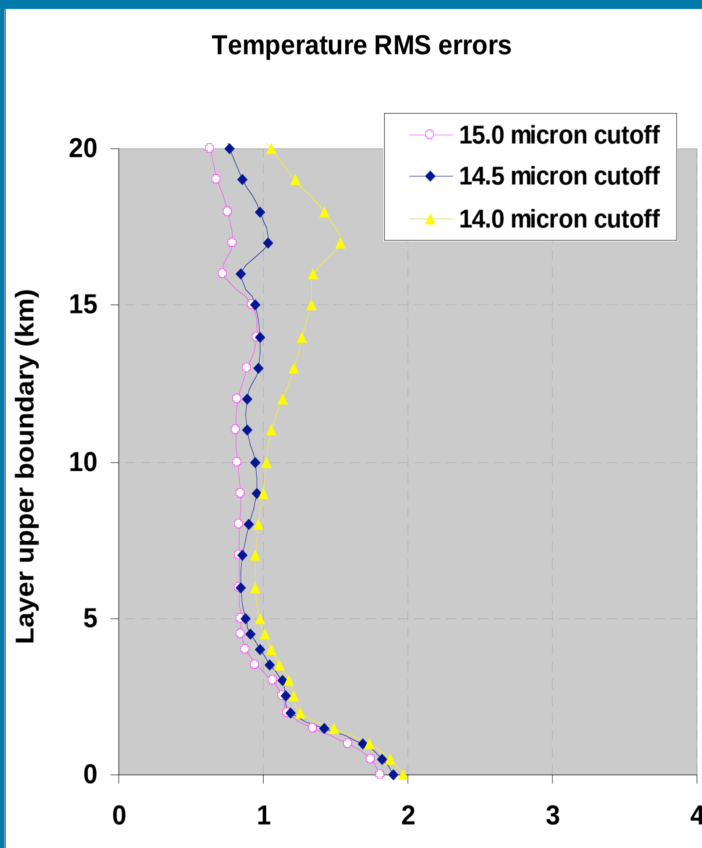
- Spatial resolution: 1-km
- Swath coverage: 1650 km (TBR)
- Radiometric Noise < 0.2K (TBR)

Measurement	Accuracy (req.'ed : goal)
Surface Temperature	1K : 0.5K
Temperature profiles	1K (rms) (1-km layers < 100mb)
Humidity profile	20% : 10% (2-km layers < 100mb)
Column Ozone	20%

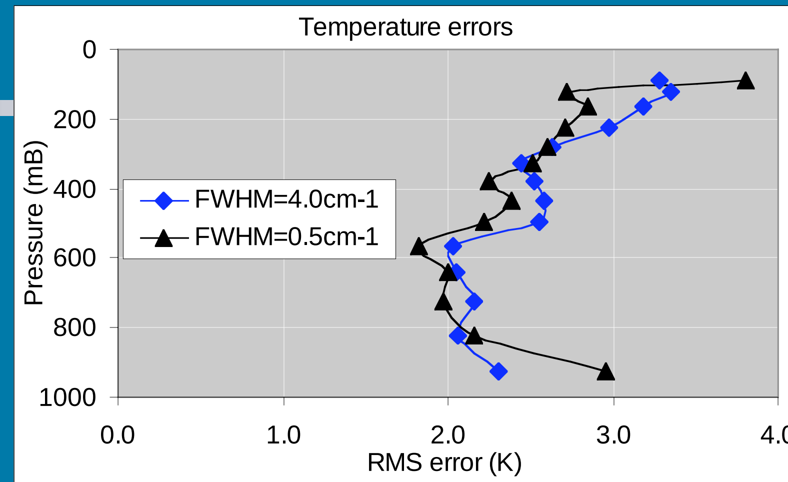
Measurement	Spectral Range (cm^{-1})	Min. res (cm^{-1})	Goal res (cm^{-1})	Notes
Temperature profiles	650 - 768 2228 - 2255 2380 - 2410	0.5 2.0 2.0	0.5	Higher spectral resolution improves T sounding throughout range
Humidity profiles	1370-1610	2.0	0.5	Weaker water lines near 2600 cm^{-1} used AIRS
Ozone Column	1001-1069	0.5	TBD	Very high resolution necessary for profile info.
Surface Temperature	750-1200	~1.0	0.5	Several channels: 750-1235 cm^{-1} and >2400 cm^{-1}
Dust properties	750-1200	~1.0	0.5	Higher resolution improves UT/LS retrievals
Cloud properties	750-1200	~1.0	0.5	3 channels: 8,10,12 mm

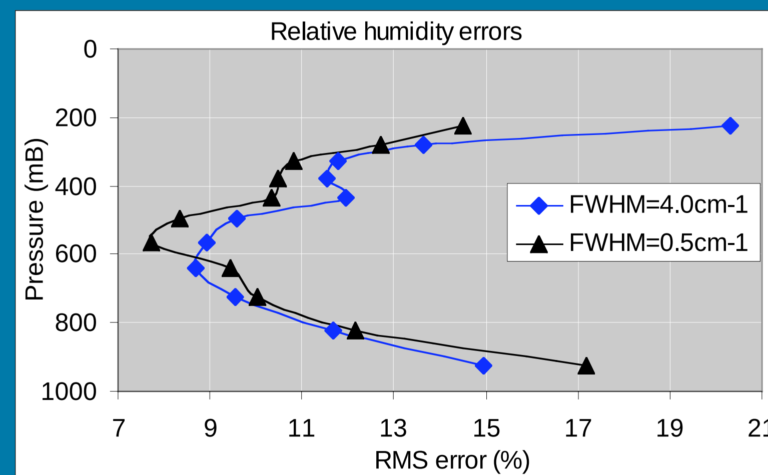
Tools In Place for Optimizing Instrument Parameters

- Retrieval simulations conducted to optimizing spectral channels, noise, resolution



Simulated temperature profile retrieval error using a linear regression technique and an ensemble of 2000 atmospheric profiles to evaluate effect of reducing long-λ FPA cutoff





Temperature (top panel) and moisture (bottom panel) retrieval errors for two spectral resolutions using MWIR band only.

Atmospheric Remote-sensing and Imaging Emission Spectrometer (ARIES)

- SIRAS-G spectrometer module is a good fit with the ARIES requirement set
- SIRAS-G is an enabling technology for ARIES proposed by Chahine et al. (JPL, NOAA/NESIS, JCSDA, GSFC, UMBC) for the Decadal Survey
- Builds on AIRS heritage
- “MODIS Spatial Resolution with AIRS Spectral Resolution and NEdT”
  - 1-km footprint
  - 3.6-15.4μm; 4800 channels; $\lambda/\Delta\lambda$=1500
- SIRAS-G spectrometer approach offers a compact instrument solution with the desired high spatial and spectral resolution
- A baseline concept will be developed for this potential mission opportunity

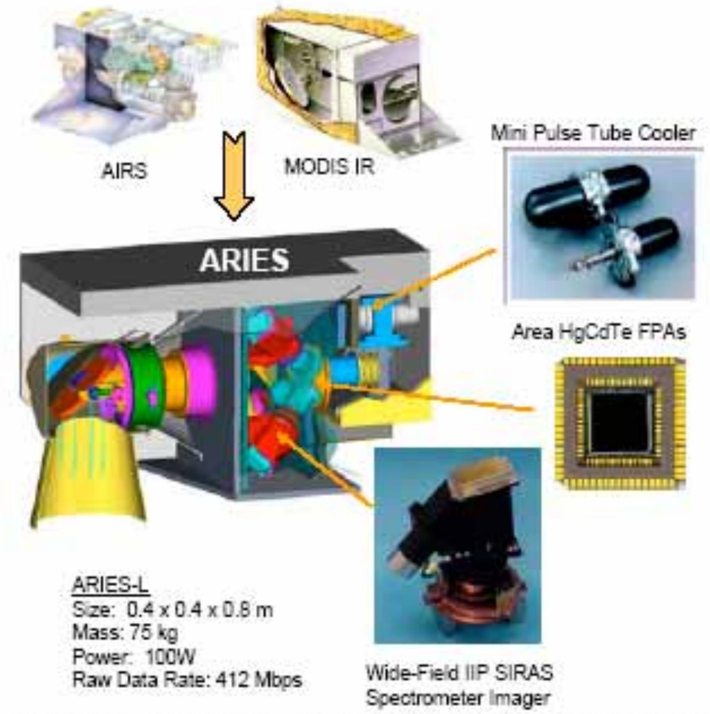


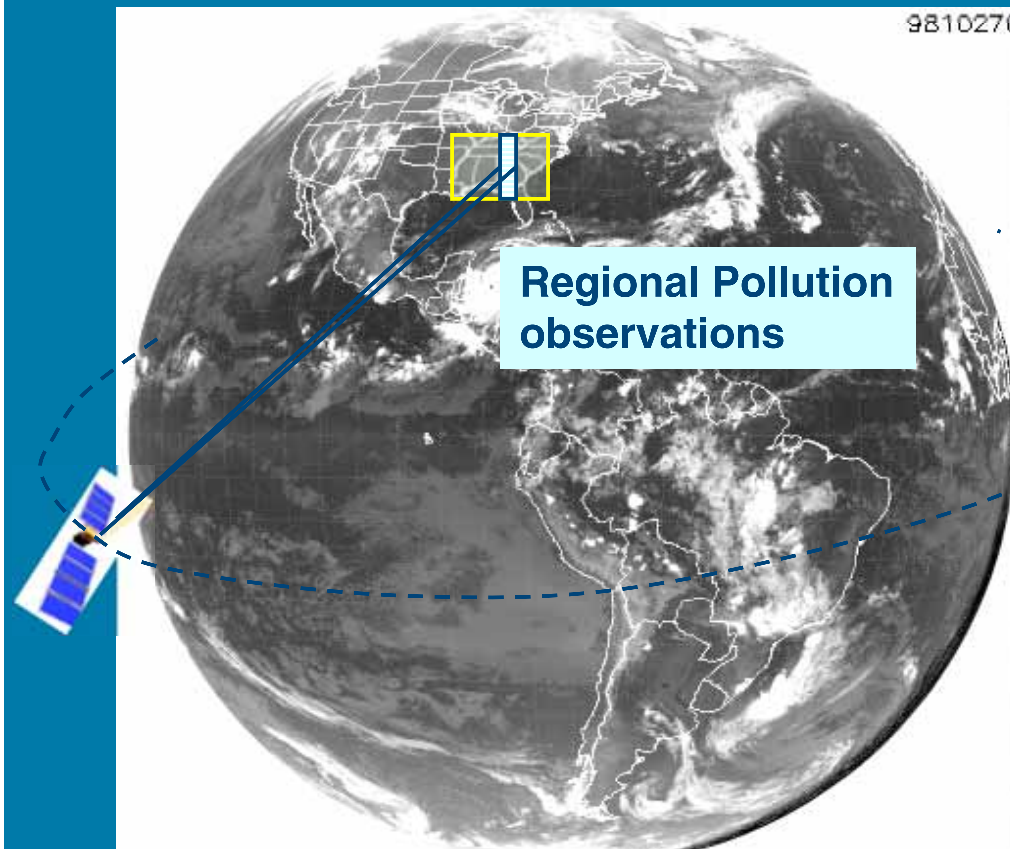
Figure 10. ARIES instrument for LEO is compact, lightweight and affordable. Uses IIP Technology.

From the ARIES Response to the NASA Decadal Survey (http://qp.nas.edu/QuickPlace/decadalsurvey/Main.nsf/h_Toc/4df38292d748069d0525670800167212/?OpenDocument

Pollution Observations from GEO

- Understanding the impact of pollution on regional, continental, and global scales imposes unique challenges for spaceborne observations.
- The variability in tropospheric chemistry, source strengths, and transport results in sub-hourly temporal variation, and produces small-scale variations in the vertical and horizontal distribution of trace gases.
- Current spaceborne observation from low earth orbit have demonstrated the capability to measure tropospheric trace gases from space but are limited to a twice daily observation. Improving the depiction of diurnal variations and small-scale transport processes requires observations from geosynchronous orbit.
- SIRAS-G enables high temporal, spatial, and spectral resolution observations of temperature, water, ozone, aerosol, cloud and surface properties, and important trace gas concentrations such as CO, CH4, N2O and SO2.
- The spaceborne instrument concept measures thermal emission over the wavelength range from 3.75 to 15 microns with a nominal resolving power ($\lambda/\Delta\lambda$) of 1200.

Pollution Observations from GEO



Notional Mission Requirements:

- UV-visible spectrometer: 310-600 nm
- Infrared spectrometer: 3.75-15 μm
- Spatial resolution 4-km
- Regional coverage in 6 minutes
- Disk coverage in 30 minutes

Measurements:

- **Temperature & humidity sounding**
- **Trace gases: O3, NO2, HCHO,CO, CH4, SO2, CO2 column, aerosols, cloud & surface properties**

The slit-image of an imaging spectrometer projected through the optical system forms a long narrow rectangle FOV. For a given slit FOV position, spatial information from the Earth scene is gathered along the length of the slit. Spectral information dispersed by the grating is simultaneously gathered along the orthogonal axis of a 2-D detector array. A full image is created by scanning the slit-FOV across the Earth disk. This measurement technique is very similar in concept to a pushbroom imaging spectrometer flying on a LEO spacecraft, for example, with "forward" motion produced mechanically by a scan mirror rather than by the orbital motion of the LEO spacecraft.

Summary

- SIRAS-G Program is nearing completion
  - Major focus now on instrument test
- Laboratory demonstration unit delivers on low volume, low mass promise
  - Major design activity complete
  - Major procurements are complete or in progress
  - Large format detector arrays allow high spectral and spatial resolution
  - Active cooling to be demonstrated
  - Test method and apparatus in place to validate performance for broad range of parameters (spectral smile, keystone distortion, SRF, MTF, dispersion)
  - Performance testing planned for Aug/Sept 2006
- Studies in progress to determine LEO & GEO applicability
  - Initial performance studies indicate high quality temperature, water, ozone retrievals are achievable with 1km spatial resolution
  - Design concepts under development for LEO and GEO missions